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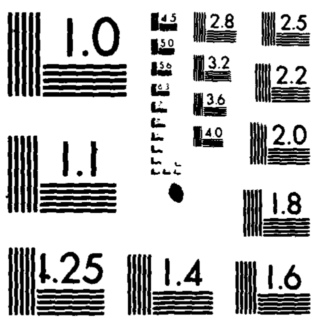
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A LEAST SQUARES APPROACH TO MISSING METEOROLOGICAL DATA

APRIL 1982

By

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Under Contract DAAD07-79-C-0008
Contract Monitor: BERNARD F. ENGEBOS

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US Army Electronics Research and Development Command
Atmospheric Sciences Laboratory
White Sands Missile Range, NM 88002

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In battlefield situations it is not uncommon to lose all or a portion of the meteorological data needed for artillery ballistic purposes due to malfunction of equipment or the balloon bursting prematurely. This report describes several techniques to provide for these missing data. Further, a preliminary comparison of these techniques is made.

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CONTENTS

INTRODUCTION 5

THE LEAST SQUARES METHOD 5

RESULTS 9

DISCUSSION 15

SPACE/TIME VARIABILITY 16

LEAST SQUARES AND OTHERS 23

SOFTWARE DOCUMENTATION 26

PROGRAM VARIABLES 30

REFERENCES 32

APPENDIX A - Program Listing 33

INTRODUCTION

A common occurrence in battlefield situations is the loss of meteorological (met) data due to malfunctions or loss of weather balloons. Recourse must be made to other existing balloon data, both contemporary and dated. For artillery purposes a complete met message is required. In this report we describe a least squares regressional analysis approach to supplying the missing meteorological data necessary to complete the met message.

Using data from the PASS (Prototype Artillery Subsystem) field experiment (1) conducted at White Sands Missile Range, New Mexico, during October - December, 1974, we have formulated several least squares routines to predict four variables from available data - wind velocity and direction, temperature, and pressure. An artillery shot was simulated on a computer by calculating an appropriate ballistic trajectory from the actual meteorological data for layers 0-4 from one balloon combined with predicted values of missing data for layers 5-9 supplied by each test routine. These results were compared to the results obtained from using the entire set of actual meteorological data as recorded by the balloon. In turn, each of the methods were intercompared to identify the best candidates for further comparisons with methods currently in use.

THE LEAST SQUARES METHOD

Each simulated shot was aimed at a target 9500 meters north of the battery, with a trajectory apex of 4000 meters (layer 9). A 155 mm howitzer with a 7W charge was used in each case, located at the met site. Using met data from surrounding sites and from layers 0-4 at the local site, a prediction was made for the meteorological parameters at layers 5-9. Following procedures from the firing tables (2) using artillery met messages (3), the artillery trajectory was calculated and compared to one made with the actual data from layers 0-9 as measured by the local balloon.

Four met sites from the PASS experiment were used. Their names, coordinates, and elevations are listed in Table 1. The artillery firings were made only from SMR and MCG. In order to sample conditions throughout the day, firings were made every hour (± 15 mins) beginning at 0600 (local time) and ending at 1600. Table 2 shows the dates and times of the firings. For each simulated firing it was necessary to have complete data from each of the four met stations for both the time of the firing and two hours previous. This severely restricted the data available for analysis, which resulted in having to select each two hour block of data from a different day. For this reason a detailed direct comparison of results as a function of time of day is not possible, but because the weather conditions were similar and stable throughout the period, we do make some inferences with regard to time of day.

Table 1. White Sands transverse mercator system coordinates of met stations (converted to meters)

Station Name	X (increases to the East)	Y (increases to the North)	Z (above mean sea level)
Small Missile Range (SMR)	144040	65614	1219
McGregor (MCG)	165731	42786	1249
Orogrande (ORO)	169896	57769	1280
LC-36 (LSX)	153348	57831	1229

Table 2. Date and Time of Selected Data

Date 1974	Local Standard Time
11/14	0545
11/11	0645
11/12	0815
11/11	0845
11/15	1000
12/02	1115
11/14	1145
11/27	1315
11/20	1345
11/08	1445
11/20	1545

For each simulated trajectory computed with actual/predicted data we constructed a measure of error attributable to the cross wind component (V_x), head wind component (V_y), temperature (t), and density (D). (The balloon-measured pressure in millibars and temperature in degrees Kelvin are used to find the density: $D = 348.4\ P/t$). This measure (Δ) is the difference in corrections determined from the firing tables converted to meters between the method using actual/predicted data and the control method using actual data for all ten levels. Combining these errors we then express a bias (β) and variance (σ^2) for each method. The total miss distance or bias is the vector sum of the cross and range miss distances:

$$\beta = [\Delta V_x^2 + (\Delta V_y + \Delta t + \Delta D)^2]^{\frac{1}{2}}.$$

The total error squared or variance is the sum of the square of the components:

$$\sigma^2 = \Delta V_x^2 + \Delta V_y^2 + \Delta t^2 + \Delta D^2.$$

Eleven different methods were tested. In each method four separate least squares analyses of the data were made, one for each variable V_x, V_y, t, and ln P, the latter two variables then being combined to form the density. Differences (Δ) between computed and actual values were combined to form β and σ^2.

In general we can express the fitting equation for a variable (say temperature) as a function of position (X and Y), altitude (Z), and time (T):

$$(1) \qquad t = a + \sum_{i=1}^{NS}(b_i X^i + c_i Y^i) + \sum_{j=1}^{NZ} d_j Z^j + \sum_{k=1}^{NT} f_k T^k.$$

If a limit is zero (i.e., NS, NT, or NZ is zero), then that variable is not included in the analysis. Vertical fits emphasize higher order terms in Z (NZ>1; NZ>NS and NT) and horizontal fits allow higher orders in X and Y (NS>1; NZ=0). Higher order terms in time were not allowed because only two times were used in the observational equations of condition, T_o and T_o - 2 (hrs). Since only four stations were used at most, NS was never more than 3, and the maximum order of Z was never greater than 5 ($NZ \leq 5$). Although there were often enough equations of condition to accomodate higher terms in Z for vertical fits, preliminary runs indicated that little was gained in expanding the order of Z beyond 5. In addition, the vertical fit for ln P was made only over Z, and not over X, Y, T, or higher powers of Z. Preliminary attempts to include them in the fitting of ln P (or P) did not indicate an improvement over ignoring them. Consequently, for vertical fits of ln P, NS = NT = 0, and NZ = 1, in all cases.

For vertical fits to a parameter, one equation with properly determined coefficients (a-f_k) suffices to yield the five missing values of the variable. For instance, once the least squares fitting equation (1) is solved for the unknown coefficients, the temperature can be predicted for layers 5-9. For horizontal fits, however, each fitting equation must be solved at each layer. Thus it takes five such equations to determine five missing temperatures.

Many more equations of conditions are available for a vertical fit (15 for two stations) than for a horizontal fit (3 equations of condition for each layer). Thus a two station vertical fit can accomodate 15 coefficients, while a horizontal fit can only accomodate 3 per layer, and must be determined separately for each of the layers where data is missing. The coefficients in a vertical fit are over determined, while in many cases one must choose which of the parameters X, Y, or T must be left out in a horizontal fit. Nevertheless, since many meteorological conditions are partitioned into layers as manifest by wind shears and inversions, a horizontal fit is appropriate in some cases.

An important characteristic of our approach is that we take the position of the balloon into account when expressing values of meteorological parameters. The value of the variable ln P, for example, is recorded at the balloon's actual position, assuming a rise rate of 300 meters/min and using the observed winds to track the balloon from one layer to the next. The missing data is supplied by the fitting equation for the position of the balloon, which facilitates comparison of the actual to predicted data at the same position and altitude.

The eleven methods tested involved one, two, or four met stations. Each station had to have a complete set of data for two hours previous to and for the time of the firing. The missing data was simulated by simply ignoring the upper 5 layers of the station containing the fictitious battery. The values of NS, NT, and NZ in equation (1) are shown below for each method a through k.

1 station

a) Vertical: NS = 0, NT = 1, NZ = 5. (NS=NT=0, NZ=1, for ln P)

b) Tacfire: Upper 5 levels at T_o are assumed to be the same as upper levels at T_o-2, but adjusted by the difference between variables at level 4.

c) Persistence: Upper 5 levels at T_o are assumed to be the same as upper levels at T_o-2, without any adjustments.

2 stations

d) Vertical: NS = 1, NT = 1, NZ = 5. (NS=NT=0, NZ = 1, for ln P).

e) Horizontal: NS = 0, NT = 1, NZ = 0.

f) Horizontal: NS = 1, NT = 0, NZ = 0.

g) Vertical and Horizontal: Same as d for temperature and ln P; same as e for V_x and V_y.

h) Vertical and Horizontal: Same as d for temperature and ln P; same as f for winds.

4 stations

i) Vertical: NS = 3, NT = 1, NZ = 5. (NS=NT=0, NZ=1, for ln P).

j) Horizontal: NS = 2, NT = 1, NZ = 0.

k) Vertical and Horizontal: Same as i for temperature and ln P; same as j for winds.

RESULTS

The results of the firings are shown in Figures 1-11, which are graphs of the bias (β) and standard error (σ), averaged between SMR and MCG, plotted against time of day for each method. Inspection of these figures reveals that all methods experienced worse results during the morning transition period than later during the day. The stability of meteorological conditions after the transition period and after the dissipation of surface based temperature inversions leads to better predictions of missing meteorological parameters by all methods.

Table 3 is a compilation of the average bias and standard error, broken down by method. Two numbers are shown for each bias and standard error. The smaller number is the average recomputed after eliminating values in excess of two standard deviations from the original (larger) averages. This is done in order to make a fair comparison with methods f and h, where attempts to use a horizontal fit resulted in wild values for the variables because only 3 equations of condition were used to determine 3 unknown coefficients. This will be discussed further below.

Figure 12 depicts the two values each of the bias and standard error before and after elimination of those values greater than two standard deviations. Because the firings were made due north with the prevailing winds out of the west, it was expected that the results from the SMR station should have been significantly poorer than from the MCG station. In fact, however, SMR outscored MCG (lower bias) by 1/3, which is interpreted as due to terrain effects. Therefore, to minimize these effects and place the emphasis on techniques instead, the averages between MCG and SMR are ued to make Table 3 and Figure 12.

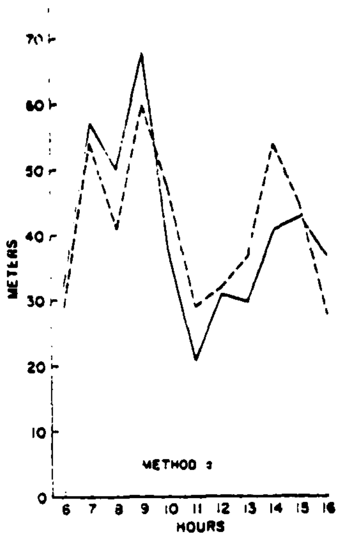
Table 3. Average bias and standard errors, (in meters) before and after elimination of extreme values

	Method	Bias: after (before elimination)	Standard error: after (before)
a		37 (40)	39 (41)
b	1 station	50 (56)	49 (55)
c		31 (33)	32 (35)
d		31 (34)	31 (34)
e		38 (44)	37 (43)
f	2 stations	44 (128)	57 (133)
g		35 (38)	37 (40)
h		53 (129)	55 (131)
i		29 (32)	30 (33)
j	4 stations	25 (28)	30 (33)
k		25 (27)	30 (31)

Figures 1-11. Figures 1 through 11, corresponding to methods a through k, are presented from left to right, top to bottom on the next two pages. In each figure the dotted line represents the standard error (σ) and the solid line the bias (β) for each method plotted against the time of day. Note the better results after mid-morning in each case.

Figure 12. The lower right figure on the second page of figures represents the overall average standard error and bias as a function of method before and after elimination of the values greater than two standard deviations. Here note that methods f and h occasionally yield wild results. This phenomenon is explained in the text.

1.


METERS
METHOD
HOURS

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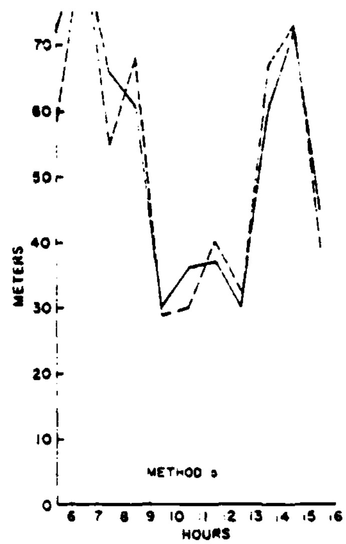
METERS
METHOD
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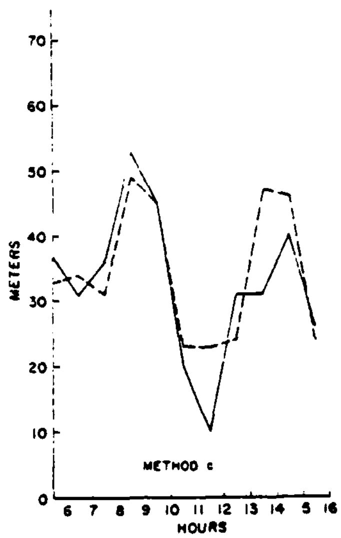
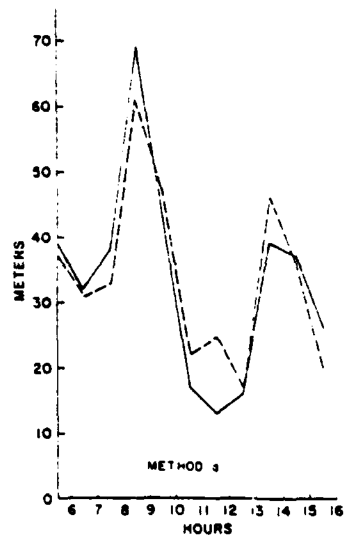
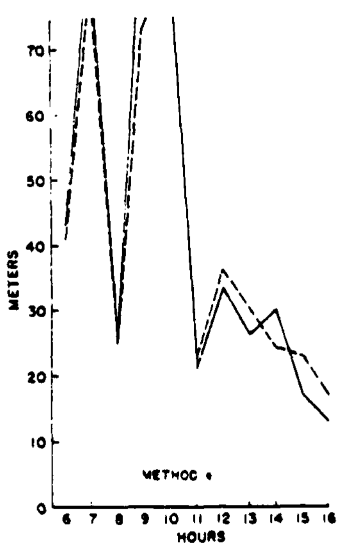

METERS
METHOD c
HOURS

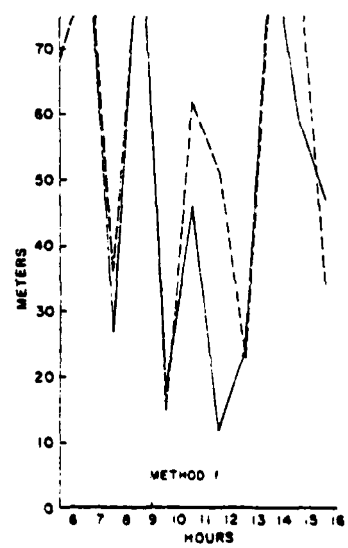
4.


METERS
METHOD
HOURS

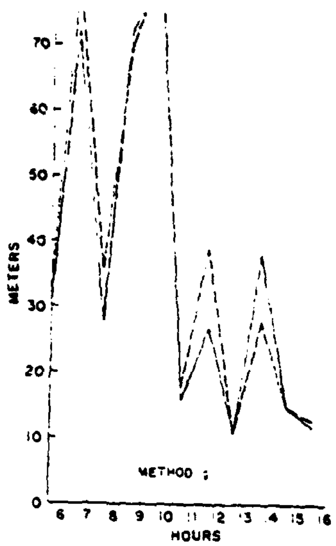
5.


METERS
METHOD e
HOURS

6.


METERS
METHOD f
HOURS

7.


METERS
HOURS
METHOD

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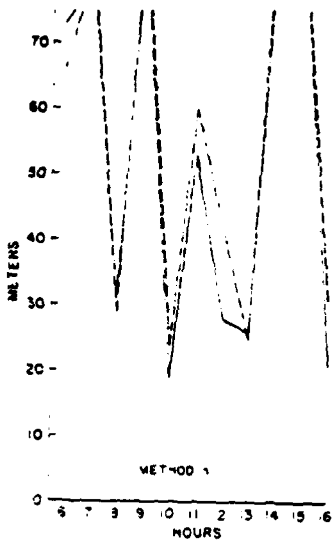
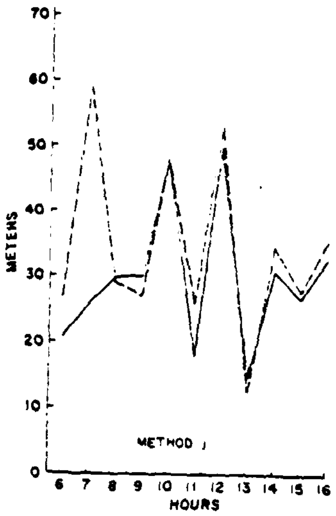

METERS
HOURS
METHOD

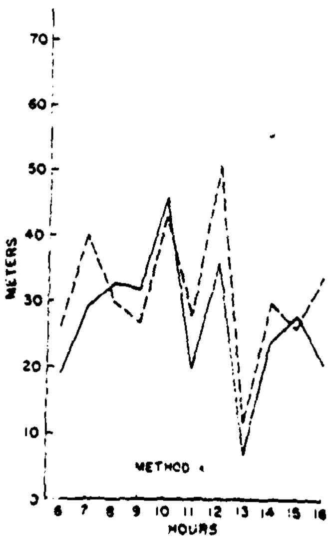
9.


METERS
HOURS
METHOD

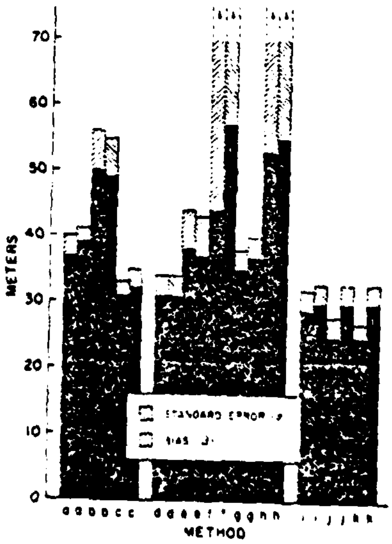
10.


METERS
HOURS
METHOD

11.


METERS
HOURS
METHOD

12.


METERS
STANDARD ERROR
BIAS
METHOD

For a consideration of the contribution of each of the components V_x, V_y, temperature, and density, to the total variance σ^2, each difference Δ was normalized by squaring it and dividing it by the total variance. From a total of 242 cases (eleven methods, at eleven times, from two stations) the following breakdown is presented.

V_y = 49.6% of total variance, ranging from 17.6% on 11/15 at 1000 at SMR to 87.3% on 11/20 at 1345 at MCG.

V_x = 23.8% of total variance, ranging from 4.7% on 11/20 at 1345 to MCG to 72.2% on 11/15 at 1000 at MCG.

temperature = 1.6% of total variance, ranging from 0.1% on many occasions to 7.0% on 11/27 at 1315 at SMR.

Density = 25.0% of total variance, ranging from 2.3% on 11/11 at 0845 at MCG to 55.3% on 11/12 at 0815 at MCG.

The contribution of each component to the bias in each of the eleven methods can be assessed by taking the average absolute value of the difference Δ for each kind of horizontal and vertical fit for 1, 2, or 4 stations. Such a breakdown by methods and type of fit is presented in Table 4. Parenthetical values for methods f and h denote inclusion of wild values.

Table 4. Average absolute values of Δ (meters)

Method	V_y	t	D	V_x
1 station				
a (vertical)	56	7	36	26
b (Tacfire)	79	5	37	37
c (persistence)	50	4	22	27
2 stations				
d (vertical)	44	5	24	29
e (horizontal)	45	8	33	42
f (horizontal)	100(242)	12(13)	49(52)	38(58)
g (horizontal/vertical)	45	5	24	42
h (horizontal/vertical)	100(242)	5	24	38(58)
4 stations				
i (vertical)	45	6	25	23
j (horizontal)	45	5	30	27
k (horizontal/vertical)	45	6	25	27

It is from such a breakdown that we selected a mixture of fits (horizontal for winds and vertical for temperature and pressure) to combine into methods g, h, and k. Since pressure is clearly best fit by the vertical methods we decided to apply a vertical fit to the temperature also, in order to keep the density in a vertical structure.

An analysis of the contribution of each of the components to the bias indicate that except for ln P, each variable is predicted about as well (or better) with a horizontal fit as with a vertical fit, if the number of equations of condition is greater (preferably much greater) than the number of unknown coefficients to be found. Physically, this indicates that the winds and temperature are stratified in the atmosphere. Mathematically, the poor results for vertical fits, despite the greater number of available equations of condition, is a product of the discontinuities associated with the interfaces of the layers. In other words, a least squares smooth fit breaks down when a sometimes nearly discontinuous variable is encountered. The fact that the vertical fits perform as well as they do can be accounted for by the over specification of the unknown coefficients in vertical fits alluded to earlier.

DISCUSSION

Regarding the persistence method as a degenerate case of a horizontal fit, where NS = NT = NZ = 0, an important finding of this report is that horizontal fits are to be preferred over vertical fits <u>when enough data exists from enough stations</u>. Let M be the "freedom", the difference between the number of equations of condition (N) and the number of unknown coefficients (P). For each method, then, Table 5 lists M, N, P, and Q, the number of times equation (1) must be solved to yield the missing 5 values of a given variable.

Obviously, M is much greater when employing a vertical fit than when attempting a horizontal regression, yet except when M=0, the horizontal is as good or better than the vertical (with the exception of fitting ln P where the vertical fit is clearly superior).

Two conclusions can be made regarding the "best" method for supplying missing data. First, the greater the number of stations the better are the results. Provided that there is enough freedom (i.e., the number of coefficients to be found is less than the number of conditional equations), a greater number of stations allows better predictions of meteorological parameters. The second conclusion, on the other hand, is that the difference between methods

Table 6. "Freedom" as a function of method

Method	M	= N	- P	; Q	
a	8	15	7	1	
b		15			no least squares fit is made
c		15			no least squares fit is made
d	26	35	9	1	
e	1	3	2	5	
f	0	3	3	5	
g	same as d for ln P and t; same as e for winds				
h	same as d for ln P and t; same as f for winds				
i	62	75	13	1	
j	1	7	6	5	
k	same as i for ln P and t; same as j for winds				

and number of stations is less than might be expected. Of the three single station methods, persistence leads to the lowest average bias and variance. In fact, it performs just as well as the best of the two station methods, a vertical fit, and only slightly poorer than the best of the four station methods.

SPACE/TIME VARIABILITY

Among the various approaches to interpolating or extrapolating meteorological data to predict missing data, a commonly considered technique involves weighting met messages according to the ages and distances of the stations. Traylor (1a) examined four techniques for use in the PASS experiment, two of which (the "weighted average" and the "plane fit") involved weighted messages. The weighted average scheme was adopted and discussed further by Stenmark et al (4) and Blanco and Traylor (5). When weights are used, an equivalence between space and time variability must be established. All of these workers assumed that the errors inherent in old or distant messages vary as the square root of the time or distance of the message, and that the equivalence between the two is between 12km/hr and 46km/hr. Traylor (1a) and Blanco and Traylor (5) chose 30km/hr while Stenmark et al (4) chose 35km/hr for their scaling factors.

In order to test these assumptions, with an eye towards incorporating weighting factors into our least squares approach, we found two times in the PASS data set when eight hours of continuous coverage was available at each station. For each of eight stations (Table 7), we used the met message that

Table 7. Separation between Coordinates of stations used for time/space variability study.

	MCG	ORO	WAR	LSX	SMR	APA	HMS	RAM
McGregor	-							
Orogrande	15.6	-						
War Road	20.8	28.7	-					
LC-36	19.5	16.6	16.5	-				
Small Missile Range	31.5	27.0	21.9	12.1	-			
Apache						-		
Holloman						37.8	-	
Rampart						25.0	39.4	-

was 8, 6, 4, and 2 hours old to make our standard artillery firing (i.e., target due north, 9500m away, trajectory apex 4000m). We then made a comparison in each case to the results from using the actual current message.

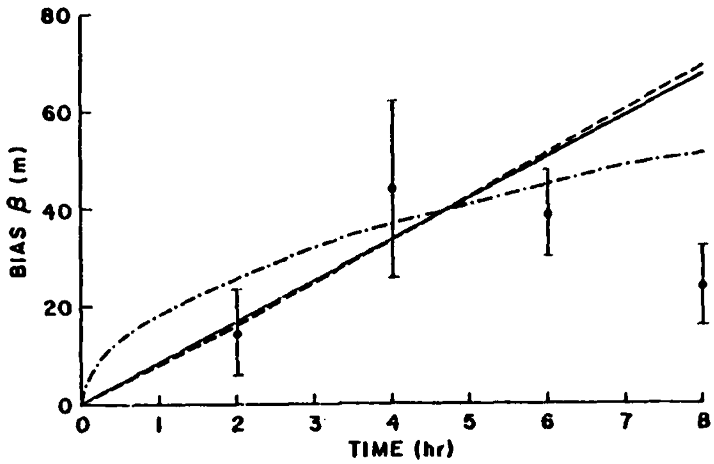
Figures 13 (November 14, 1200 ± 0015) and 14 (November 15, 1215 ± 0015) are plots of the average bias for each of the eight stations over time, with the standard deviation from the average illustrated as an error bar on each point. Also shown in each figure are curves fitted to the first three points only (2, 4, and 6 hours). Eight hour old data dropped toward lower biases compared to six hour old data. Consequently, eight hours were not considered in the fittings. Table 8 shows the numerical values of the results of the fits. The t^2 fit is not shown in the figure.

Table 8. Functional dependence of Bias (β) over time

	Function	Standard error
11/14	$18.28\sqrt{t}$	13.55
	$7.95\ t^{1.04}$	13.45
	$8.46\ t$	13.08
	$1.60\ t^2$	25.03
11/15	$22.84\sqrt{x}$	28.53
	$8.29\ t^{1.08}$	20.62
	$10.57\ t$	18.81
	$2.00\ t^2$	13.61

Figure 13. - (Top of next page). Bias vs. time for November 14, 1974 at 1145 for MCG, ORO, WAR, LSX, and SMR, and 1215 for APA, HMS, and RAM. Three fits over the first three points are shown: a square root fit is denoted by the dot-dash line, a linear fit by the solid line, and a power fit by the dashed line. The standard deviation from the mean is shown as an error bar on each point. The total length of the bar is 2σ. The numerical values for the fits are given in Table 7.

Figure 14. - (Bottom of next page). Same as for Figure 13, but for November 15, 1974 and 15 minutes later. See Table 8 for the numerical values for the fits.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2
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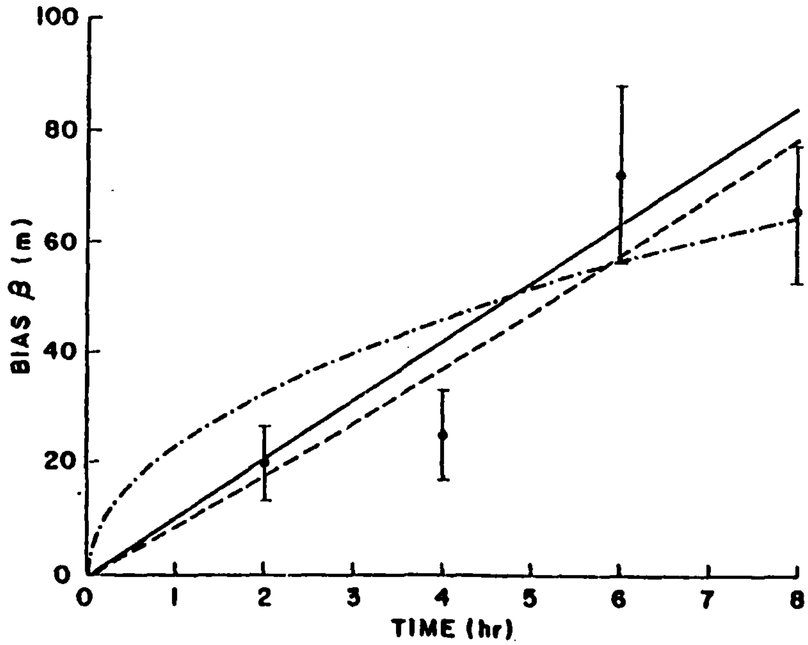
5
6
7
8
TIME (hr)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8
TIME (hr)

Similarly, current met messages from every other station were used in turn as a substitute for the actual message of each station. The biases were calculated and are plotted as a function of station separation in Figures 15 and 16. Table 9 is the result of fitting all of the distance points. The x^2 fit again is not shown in the figures in order to reduce the clutter of too many lines. Because the HMS, APA, and RAM sites released their balloons 30 minutes after the other five stations, they are treated separately. The three were not used to supply a current met message to any of the five stations, and vice-versa.

Table 9. Functional dependence of Bias over space

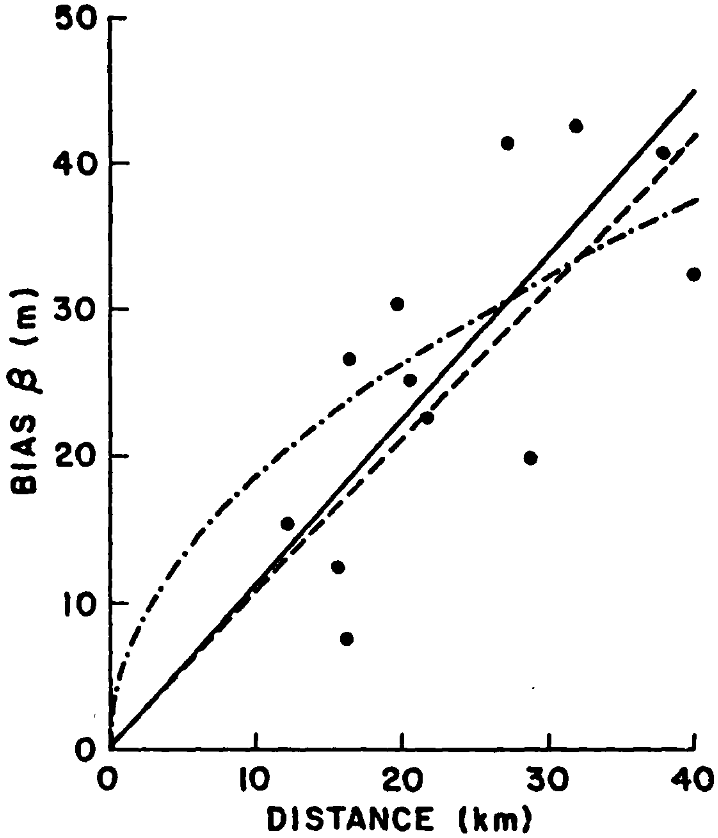
	Function	Standard error
11/14	$5.88\sqrt{x}$	9.26
	$1.09\ x^{.99}$	9.23
	$1.13\ x$	8.81
	$0.037\ x^2$	13.69
11/15	$3.64\sqrt{x}$	7.56
	$1.18\ x^{.80}$	8.23
	$.70\ x$	8.43
	$0.023\ x^2$	11.86

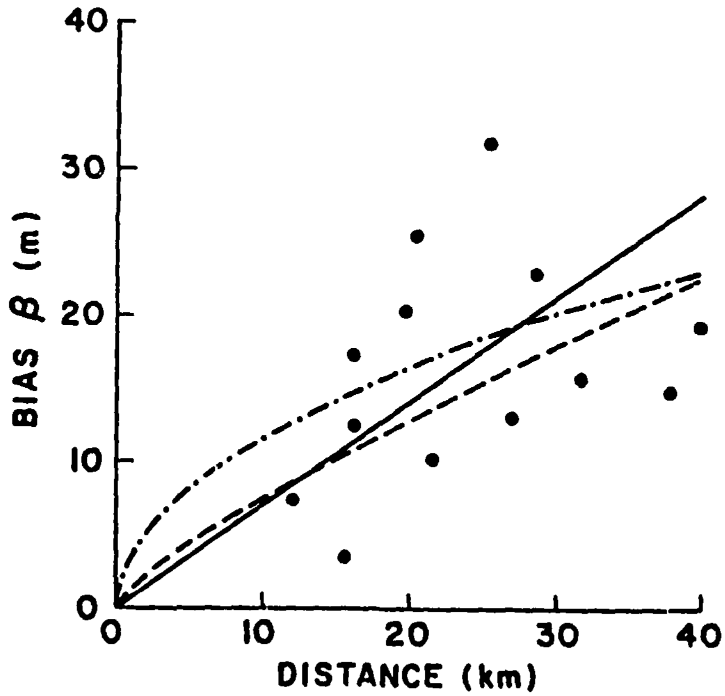
Examining Figures 13-16, it is not easy to select the best fit. The residuals from the fits (expressed in Tables 8 and 9 in the standard errors) do not indicate a significant difference between functional forms of variation either. There is little reason to choose a linear, square root, or power relationship over either distance or time. Only a quadratic fit can be eliminated as inferior, although it does give the best fit over time on 11/15 according to the standard errors. The assumption of a square root dependence of variability on time and space does not appear to be justified, but from the sparse data analyzed here it is no worse than any other assumption. Therefore, to continue with our analysis we will maintain this assumption.

If $\beta_x = C_1\sqrt{x}$ and $\beta_t = C_2\sqrt{t}$ is assumed, then by equating β_x and β_t we can find the equivalence between time and space variability:

Figure 15. - (Top of next page). Bias vs. distance for November 14, 1974 at 1145 or 1215. Three fits to all of the station separation (Table 7) points are shown with the same codes as in Figure 13. See Table 9.

Figure 16. - (Bottom of next page). Same as Figure 15, but for November 15, 1974, at 1200 or 1230. See Table 9.


50
40
30
20
10
0
BIAS β (m)
0
10
20
30
40
DISTANCE (km)


40
30
20
10
0
BIAS β (m)
0
10
20
30
40
DISTANCE (km)

$$\frac{\beta_x}{\beta_t} = \frac{C_1 \sqrt{x}}{C_2 \sqrt{t}}$$

or

$$\frac{C_2}{C_1} = \frac{\sqrt{x}}{\sqrt{t}} = \sqrt{\gamma} ,$$

where γ is the scaling factor (in units of km/hr) for equating space and time variation.

On November 14 γ is $(18.28/5.88)^{\frac{1}{2}}$ = 9.7km/hr and on the 15th $(22.84/3.64)^{\frac{1}{2}}$ = 39.4km/hr. Recalling that γ is usually taken to be 30 to 35km/hr, we claim that the range of γ found here on two consecutive days suggests that adopting a single value for γ or even a single, universal weighting system, can lead to poorer results than a no weighting scheme. Intuitively, it is felt that γ does actually vary from day to day; there is no reason to assume that the scale length of variation of meteorological parameters over time and/or space remains unchanged. In fact, γ is probably a strong function of wind velocity and wind variability. A strong steady wind will undoubtedly reduce γ relative to a no wind condition, since it would take less time for a change in a meteorological parameter to be transmitted over a distance in a strong wind than when it is calm.

Blanco and Traylor (5) used a γ of 30km/hr associated with a C_1 of 0.47 and a C_2 of 2.5. While their γ is roughly similar to ours, their C_1 and C_2 are an order of magnitude smaller than ours on either the 14th or 15th. Although this may be due to their use of 8-inch howitzer firing tables where we used the 155mm tables, it nevertheless emphasizes the danger and futility of adopting a single γ or a universal weighting system. If weights are to be used, it is better to determine γ and the weights from available data each day.

LEAST SQUARES AND OTHERS

A fundamental difference between our least squares approach and the apparently preferred weighted average is that the latter cannot extrapolate to values of a parameter outside the range already experienced, whereas the former can predict new values. For instance, suppose that the measured temperature at time T_o-6, T_o-4, and T_o-2 were, 80°, 82°, and 84°, respectively. A least squares prediction for the temperature at T_o would be 86°, but a weighted average prediction would range between 80° and 84° depending on the weights employed. Thus, because the least squares estimator is not constrained to a range, it can serve as a better predictor. This is a desirable feature, expecially since met stations are often asked to extrapolate meteorological conditions to outside the cloud of stations, to an artillery battery located at or nearer a battlefront.

On the other hand, if the data results are an ill-conditioned problem, a least squares estimate of extrapolated values can lead to absurd results. If two stations are located 1 km apart and measure the surface temperature at 80° and 82°, a least squares prediction of the temperature at a station 25 km away would be 130°. The weighted average in this case would surely lead to a better prediction. However, if the met stations are roughly equally spaced, and they are asked to furnish predictions of parameters not too far away in time or space (say not more than the average spacing of the stations or longer than the time over which data was gathered), then we feel that a least squares approach represents the least biased method to adopt. In fact, any weighting scheme (including a weighted least squares) will ultimately compromise the potential accuracy of predictions since appropriate weights and scaling factors vary widely and are generally unknown.

Another method, the cubic spline technique, was examined by D'Arcy (1b) as a possible interpolation/extrapolation scheme, but it was found "that the spline can be a rather poor predictor" because in extrapolation "as one gets further from the last measured point the slope of the curve increases without bound." Our least squares approach appears to offer the possibility of better predictions because unlike the cubic spline, only one polynomial needs to be solved for each variable, and not a polynomial and its first and second derivatives.

More testing needs to be performed to explore the power and delineate the limitations of the least squares approach to extrapolating and interpolating missing meteorological data. Certainly a safety factor should be employed to prevent absurd values under unusual conditions. The limits for extrapolation in space and time need to be established from more tests under various circumstances. In addition, the inferences made concerning space/time variability should be confirmed with more examples. In order to properly test a 30 km/hr scaling factor, tests over 6 hours of data should be compared to tests over

(6x30=) 180 km, whereas we only tested 6 hours of data and 40 km because of the close station separations. The choice of square root, linear, or power relations between bias and space/time might be resolved with more data. Certainly a greater distance should be covered than that shown in Figures 15 and 16, and a greater density of points in time should be used than that shown in Figures 13 and 14.

The testing that we have done on our least squares method shows that it has great potential for extrapolating and interpolating data. At the very least we feel that the method is a viable alternative to any in use today. The computer code as it exists now (to be documented under separate cover) is not a data management system (which is a necessary and important part of the overall program). However, it is flexible enough to be considered appropriate to adapt to a variety of data storage systems. Least squares is an unbiased and rather unsophisticated approach to the problem of missing meteorological data, but at the same time it is simple and fairly powerful, easily adaptable for field artilley use.

SOFTWARE DOCUMENTATION

1.0 INTRODUCTION

This documentation pertains to a least squares regressional analysis approach to missing meteorological data, developed in 1981. This approach relys on a combination of horizontal and vertical least squares fits to predict missing wind velocity and direction, temperature, and pressure. The fitting equations are varied by means of parameters input from data cards. Parameters affecting the fitting equations are the number of zones making up a met profile, the number of met stations considered, the number of different times considered, and the physical location of the contributing met stations.

Using data from seven different stations collected over a three month period, predictions of pseudo-missing data were made. Various combinations of input stations, times, locations, and number of missing layers were tried. These predictions were then used for a simulated artillery shot and the results compared with the actual data measured at the point of interest.

Due to the fact that this approach uses all available data as input, only missing data from one site at a time may be predicted. Obviously, well behaved input will provide more accurate results, which will enhance the value of the predictions as input to later predictors. Hence, it is well worth the effort, if possible, to analyze and discard rough or inaccurate inputs.

At this stage of development, this software would be a valuable "front-end" tool for artillery meteorological units.

2.0 INPUT

Card Input

Cols.	Format	Name	Description
CARD ONE:			
1-3	I3	NS	Number of sites input
4-6	I3	NT	Number of times input
7-9	I3	NZ	Number of zones
CARD TWO:			
1-8	F8.0	CX	X coordinate of sta.
9-16	F8.0	CY	Y coordinate of sta.
17-24	F8.0	CZ	Z coordinate of sta.
25-32	F8.0	THR	Hour of met message
33-40	F8.0	TMIN	Minute of met message
CARD THREE:			
1-12	2(A6)	SITE	Two word array containing site ID, time and date to be read from mass storage device
CARD FOUR:			
1-2	I2	NZONS	Number of layers in profile defined by card three
CARD FIVE:			
1-3	I3	NINPRO	Number of layers in each met profile
4-6	I3	MISLYR	Number of missing layers to be predicted

Card two is repeated for each profile input. The values on the first card two become the values of the origin. The values on the last card two pertain to the station with missing data.

In the present configuration, cards three and four are repeated as a pair. One pair for each card two. This will change as the software is implemented with different data input devices and formats.

Cards one and five are both read in from the main program and neither their number nor position should change.

Currently, test data is read from mass storage using logical unit seven. This data is in a Fortran formatted file. Each profile consists of twelve lines of data, a header line in the same format as input card three, ten data lines consisting of layer number, wind direction, wind speed, temperature, and pressure. The data lines are formatted, I2, I3, I3, I5, I4, and the last data line is followed by a line containing 99, which denotes the end of profile.

3.0 OUTPUT

Program output is currently directed to a line printer, logical unit six. Output consists of two parts, the first part is merely an echo of the input coordinates and times printed in a 5(F8.0) format. The second part of the output is the met profile of interest, with the actual data as far as it were available and predictions finishing out the profile. These data are printed in the following format:

> Layer Number (I4), Wind Direction (F10.3), Wind Speed (F10.3), Temperature (F10.1), and Pressure (F10.0).

4.0 OPERATING INSTRUCTIONS

The program will be provided on two media, punched card and nine-track magnetic tape.

Punched card decks contain all necessary control cards to compile and assemble the routines into an absolute element. Identical source language and control cards are on tape in a file called 8102*PREDICT..

Source programs are in FORTRAN V. Only one change is necessary to convert to ASCII Fortran. The four @FOR,IS cards need to be changed to @FTIN,IS. All other cards and procedures remain the same.

PROGRAM VARIABLES

I. Variables In Common

CX, CY, CZ	=	X,Y,Z coordinates of each net station
INDEX	=	An error indicator from LSTSQR not currently being output
JZONS	=	The total number of layers input
NA, NB, NQ, N, M	=	Input arguments to LSTSQR
NINPRO	=	The number of layers in the net profile
NSITES	=	The number of profiles input
NZONS	=	Input value giving the number of layers in the input profile
Range & Cross	=	Measured X and Y displacements at each level
SE	=	Output standard error of single equation from subroutine LSTSQR
TEMP & PRES	=	Measured temperature and pressure values at each level
THEATA	=	The input wind direction in miles
THR & MIN	=	The hour and minute time log for each profile
TRANGE	=	Predicted value of range
TCROSS	=	Predicted value of cross
TPRES	=	Predicted value of pressure
TTEMP	=	Predicted value of temperature
VEL	=	Input wind velocity in knots
X, Y, Z, T	=	Cummulative X, Y, Z and time balloon displacement computed from the origin

II. Local Variables In Main

A	=	Input array of coefficients for LSTSQR
CC, OMCC, CE	=	Intermediate arrays used to compute predictions
DELT	=	Difference between T (lstkwn) and T (lstkwn-1)
DELZ	=	Difference between Z (lstkwn) and Z (lstkwn-1)
LSTKWN	=	INDEX at last known X, Y, Z and time
MISLYR	=	Number of missing byers
NS	=	Number of different sites input
NT	=	Number of different times input
NZ	=	Number of zones input
RQ, OMC, C	=	Output arrays from LSTSQR

III. Local Variables in LSTSQR

A = Coefficients of observational equations

C = Computed value for all observatioal equations

ØMC = Observed - Computed for all observational equations

Q(N,J) = X(J) the unknowns

Q(I,J) = The weights of the unknowns

Q(N,N) = The sum of the (Ø-C) squared

R(I,J) = The coefficients of the normal equations

R(N,J) = The standard error of the unknowns

R(N,N) = The sum of the (Ø-C) squared, calculated from ØMC and used to calculate SE

SE = The standard error of a single equation of unit weight

IV. Local Variables in READER

Header = Two word array with site id, date and time, read from mass storage

SITE = Two word array containing site id, date and time of interest

ITHETA = Temporary variable used to read integer wind direction, units are 10's of mils

IVEL = Temporary variable used to read integer wind velocity in whole knots

ITEMP = Temporary variable to read integer temperature, units are tenth's of degrees

IPRES = Temporary variable used to read integer pressure in millibars

V. Local Variables in CØEF

All variables except indices in CØEF are contained in common.

REFERENCES

1) Barnett, Kenneth M., 1976, "A Description of the Artillery Meteorological Comparisons at White Sands Missile Range, October 1974 - December 1974 ('PASS' - Prototype Artillery (Meteorological) Subsystem)," ECOM-5589, Atmospheric Sciences Laboratory, US Army Electronics Command, White Sands Missile Range, NM.

1a) Traylor, Larry E., ibid. p. 35. "'Mean-Weighted' Computer Met Messages."

1b) D'Arcy, E. M., ibid. p. 42 "'Extrapolated-Interpolated' Computer Met Messages."

2) FT 15-AH-2, 1965, "Firing Tables", Headquarters, Department of the Army, Washington, DC.

3) FM 6-15, 1970, <u>Artillery Meteorology</u>, Headquarters, Department of the Army, Washington, DC.

4) Stenmark, Ernest B., Ohmstede, William D., and Veazey, Don R., 1977, "Proposed AMS-A for CORPS TACFIRE (PACT) System Description", Internal Report Atmospheric Sciences Laboratory, US Army Electronics Command, White Sands Missile Range, NM.

5) Blanco, Abel J. and Traylor, Larry E., 1976, "Artillery Meteorological Analysis of Project Pass," ECOM-5804, Atmospheric Sciences Laboratory, US Army Electronics Command, White Sands Missile Range, NM.

APPENDIX A

Program Listing

```
@FOR,IS MAIN
      COMMON /AB/ SE,CX(13),CY(13),CZ(13),THR(13),TMIN(13),
     1THETA(340),VEL(340),NINPRO,
     1X(340),Y(340),Z(340),T(340),
     1RANGE(340),CROSS(340),TEMP(340),PRES(340),
     1TRANGE(26),TCROSS(26),
     1TTEMP(26),TPRES(26),
     1NZONS(13),JZONS,NSITES
     1,NA,NB,NQ,N,M,INDEX
C
C  DEFINITION OF VARIABLES IN COMMON
C
C  SE=OUTPUT STANDARD ERROR OF SINGLE EQUATION
C     FROM SUBROUTINE LSTSQR
C  CX,CY,AND CZ=X,Y,Z COORDINATES OF EACH MET STATION
C  THR AND TMIN= THE HOUR AND MINUTE TIME TAG FOR EACH PROFILE
C  THETA= THE INPUT WIND DIRECTION IN MILLS
C  VEL= THE INPUT WIND VELOCITY IN KNOTS
C  NINPRO= THE NUMBER OF LAYERS IN THE MET PROFILE
C  X,Y,Z,T= CUMULATIVE X,Y,Z,AND TIME BALLOON DISPLACEMENTS
C      COMPUTED FROM THE ORIGIN
C  RANGE AND CROSS= KNOWN X AND Y DISPLACEMENTS AT
C      EACH LEVEL
C  TEMP AND PRES=  KNOWN TEMPERATURE AND PRESSURE VALUES
C      AT EACH LEVEL
C  TRANGE,TCROSS TTEMP,AND TPRES= PREDICTED VALUES OF
C      RANGE,CROSS,TEMP,AND PRES
C  NZONS= INPUT VALUE GIVING THE NUMBER OF LAYERS IN
C      THE INPUT PROFILE
C  JZONS= THE TOTAL NUMBER OF LAYERS INPUT
C  NSITES= THE NUMBER OF PROFILES INPUT
C  NA,NB,NQ,N,M= INPUT ARGUMENTS FOR LSTSQR
C  INDEX= AN ERROR INDICATOR FROM LSTSQR WHICH IS NOT
C      CURRENTLY BEING OUTPUT
      DOUBLE PRECISION A(340,33),R(33,33),Q(33,33),OMC(340),C(340)
      DOUBLE PRECISION CG
      DOUBLE PRECISION CC(340),OMCC(340),CE(340)
C
C  LOCAL VARIABLES
C
C  A= INPUT ARRAY OF COEFFICIENTS FOR LSTSQR
C  R,Q,OMC,AND C = OUTPUTS FROM LSTSQR
C  CC,OMCC,CE= ,INTERMEDIATE ARRAYS USED TO COMPUTE PREDICTIONS
C  NS= NUMBER OF DIFFERENT SITES INPUT
C  NT= NUMBER OF DIFFERENT TIMES INPUT
C  NZ= NUMBER OF ZONES
C  MISLYR=  NUMBER OF MISSING LAYERS
C  LSTKWN=  INDEX OF LAST KNOWN X,Y,Z,AND TIME
C  DELT=  DIFFERENCE BETWEEN T(LSTKWN) AND T(LSTKWN-1)
C  DELZ=  DIFFERENCE BETWEEN Z(LSTKWN)AND Z(LSTKWN-1)
       READ(5,98)NS,NT,NZ
98    FORMAT(3(I3))
      NA=340
      INDEX=1
      NB=33
      NQ=33
      NSITES=NS*NT
      CALL READER
      CALL COEF
      READ(5,199)NINPRO,MISLYR
199   FORMAT(I3,I3)
      KNOWN=(NSITES-1)*NINPRO
      ICUT=NINPRO-MISLYR
      II=ICUT
```

```
      LSTKWN=KNOWN+ICUT
      NN=0
      NM=0
      II=II+K
      NN=((IOPT-1)*340)
      NZZ=NZ
      NSS=NS
      NTT=NT
      DO 600 IOPT=1,3
      NZ=NZZ
      NS=NSS
      NT=NTT
      IF(IOPT.GE.3)GO TO 2000
C  BEGIN HORIZONTAL FIT
      I=1
      J=1
       M=NS*NT-1
      GO TO 2
3     J=J+1
      GO TO 2
4     I=I+1
2     N=1+2*(NS-I)+(NT-J)
      IF(M.GT.N)GO TO 1000
      IF((NS.EQ.1).AND.(NT.EQ.2))GO TO 1000
      IF(N.LE.1)GO TO 2000
      IF((NT-J).GT.(NS-I))GO TO 3
      GO TO 4
1000  NZ=0
      GO TO 2200
C  BEGIN VERTICAL FIT
2000  IF(NZ.GT.5) NZ=5
      IF(IOPT.EQ.4)GO TO 2010
      GOTO 2080
2010  NS=1
      NT=0
      NZ=1
2080  I=1
      J=0
      K=0
      M=NZZ*NS*NT-MISLYR
3100  J=J+1
3200  N=1+2*(NS-J)+NT-J+NZ-K
      IF(M.GT.N)GO TO 2100
      IF(N.LE.(NZ-K+1))GO TO 4000
      IF((NT-J).GT.(NS-I)) GO TO 3100
      I=I+1
      GO TO 3200
4000  K=K+1
      GO TO 3200
2100  NZ=NZ-K
2200  NT=NT-J
      NS=NS-I
      N=N+1
       IF(IOPT.EQ.3)GO TO 700
      GO TO 500
C  500 COMPUTES THE A ARRAY FOR HORIZONTAL FIT
500   DO 117 LUP=1,MISLYR
      II=II+LUP
      NM=0
      NN=((IOPT-1)*340)
C
C  DECISION FOR HORIZONTAL OR VERTICAL FIT
C
      IF(IOPT.LE.2)LOPSIZ=NSITES
      IF(IOPT.EQ.3)LOPSIZ=JZONS
      LST=LSTKWN-1
```

```
      DELT=T(LSTKWN)-T(LST)
      DELZ=Z(LSTKWN)-Z(LST)
      MM=NN
      DO 5 I=1,LOPSIZ
      J=II+NN
      JJ=II+NM
      IF(I.GT.M)X(JJ)=X(LSTKWN)
      IF(I.GT.M)Y(JJ)=Y(LSTKWN)
      IF(I.GT?M)T(JJ)=T(LSTKWN)+(DELT*LUP)
      IF(I.GT.M)Z(JJ)=Z(LSTKWN)+(DELZ*LUP)
      A(I,1)=1.
      IF(NS.EQ.0)GO TO 11
      DO 10 K=1,NS
      KK=K+1
      KKK=KK+NS
      A(I,KK)=X(JJ)**K
10    A(I,KKK)=Y(JJ)**K
11    CONTINUE
      IF(NZ.EQ.0)GO TO 21
      DO 20 K=1,NZ
      NY=K+1+(2*NS)
20    A(I,NY)=Z(JJ)**K
21    CONTINUE
      IF(NT.EQ.0)GO TO 31
      DO 30 K=1,NT
      IN=K+1+(2*NS)+NZ
30    A(I,IN)=T(JJ)**K
31    CONTINUE
      IND=NN+I
      A(I,N)=RANGE(J)
      NN=NN+NINPRO
      NM=NM+NINPRO
5     CONTINUE
C
C CALL LSTSQR TO PREDICT MISSING WIND LAYER
C
      CALL LSTSQR(A,R,Q,OMC,C)
      CG=0
      INDX=N-1
      DO 188 IT=1,INDX
      CG=CG+Q(N,IT)*A(NSITES,IT)
188   CONTINUE
      IF(MM.GT.0)GO TO 113
      TRANGE(II)=CG
       GO TO 117
113   CONTINUE
      TCROSS(II)=CG
117   II=ICUT
111    CONTINUE
      DO 118 I=1,ICUT
      K=I+KNOWN
      TRANGE(I)=RANGE(K)
118   TCROSS(I)=CROSS(K)
      GO TO 12
121   CONTINUE
700   NN=((IOPT-1)*340)
      IF(IOPT.LE.2)LOPSIZ=NSITES
      IF(IOPT.EQ.3)LOPSIZ=JZONS
C
C  COMPUTES A  ARRAY FOR VERTICAL TEMPERATURE FIT
C
      DO 15 I=1,LOPSIZ
      IF(I.GT.M)X(I)=X(M)
      IF(I.GT.M)Y(I)=Y(M)
      IF(I.GT.M)T(I)=T(I-1)+DELT
      IF(I.GT.M)Z(I)=Z(I-1)+DELZ
```

```
      MM=NN
      A(I,1)=1.
      IF(NS.EQ.0)GO TO 411
      DO 410 K=1,NS
      KK=K+1
      KKK=KK+NS
      A(I,KK)=X(I)**K
410   A(I,KKK)=Y(I)**K
411   CONTINUE
      IF(NZ.EQ.0)GO TO 421
      DO 420 K=1,NZ
      NY=K+1+(2*NS)
420   A(I,NY)=Z(I)**K
421   CONTINUE
      IF(NT.EQ.0)GO TO 431
      DO 430 K=1,NT
      IN=K+1+(2*NS)+NZ
430    A(I,IN)=T(I)**K
431   CONTINUE
      IND=NN+I
      A(I,N)=RANGE(IND)
15    CONTINUE
C
C CALL LSTSQR TO PREDICT MISSING TEMP LAYERS
C
      CALL LSTSQR(A,R,Q,OMC,C)
      L=1
      MM=M+1
      IA=KNOWN+NINPRO
      DO 88 I=MM,IA
      INDX=N-1
      DO 187 IT=1,INDX
      CC(L)=CC(L)+Q(N,IT)*A(I,IT)
187   CONTINUE
      OMCC(L)=A(I,N)-CC(L)
      L=L+1
88    CONTINUE
      NM=JZONS-M
      MN=KNOWN+1
      MM=MN
      DO 33 I=1,ICUT
      K=I+KNOWN
      TTEMP(I)=TEMP(K)
33    CONTINUE
      L=1
      IB=NINPRO-MISLYR+1
      DO 32 I=IB,NINPRO
      TTEMP(I)=CC(L)
      L=L+1
32    CONTINUE
12    CONTINUE
600   CONTINUE
      M=KNOWN+(NINPRO-MISLYR)
      N=3
C
C  COMPUTES A  ARRAY FOR VERTICAL PRESSURE FIT
C
      DO 211 I=1,JZONS
      A(I,1)=1.D0
      A(I,2)=Z(I)
      IF(PRES(I).GT.0.)A(I,3)=DLOG(PRES(I))
      IF(PRES(I).EQ.0.)A(I,3)=0.
211    CONTINUE
C
C CALL LSTSQR TO PREDICT MISSING PRES LAYERS
C
```

```
      CALL LSTSQR(A,R,Q,OMC,C)
      MM=M+1
      DO 222 I=MM,JZONS
222   C(I)=Q(N,1)*A(I,1)+Q(N,2)*A(I,2)
      DO 987 I=1,JZONS
      CE(I)=DEXP(C(I))
987   CONTINUE
      MN=KNOWN+1
      MM=MN
      DO 338 I=1,ICUT
      TPRES(I)=PRES(MN)
      MN=MN+1
338    CONTINUE
      IB=NINPRO-MISLYR+1
      DO 339 I=IB,NINPRO
      TPRES(I)=CE(MN)
      MN=MN+1
339    CONTINUE
C
C  CONVERT PRESDICTED VALUES BACK TO STANDARD MET UNITS
C
      DO 341 I=1,NINPRO
      TDIR=ATAN(TRANGE(I)/TCROSS(I))
      TDIR=(TDIR/(2*3.14159))*6400.
      TDIR=4800-TDIR
      IF(TDIR.LT.0.)TDIR=TDIR+6400.
      TVEL=(SQRT((TRANGE(I)**2)+(TCROSS(I)**2)))/(.51444444*60.)
      WRITE(6,1357)I,TDIR,TVEL,TTEMP(I),TPRES(I)
1357  FORMAT(1X,I4,F10.3,F10.3,F10.1,F10.0)
341   CONTINUE
      STOP
      END
```

```
@FOR,IS LSTSQR
      SUBROUTINE LSTSQR(A,R,Q,OMC,C)
      COMMON /AB/ SE,CX(13),CY(13),CZ(13),THR(13),TMIN(13),
     1THETA(340),VEL(340),NINPRO,
     1X(340),Y(340),Z(340),T(340),
     1RANGE(340),CROSS(340),TEMP(340),PRES(340),
     1TRANGE(26),TCROSS(26),
     1TTEMP(26),TPRES(26),
     1NZONS(13),JZONS,NSITES
     1,NA,NB,NQ,N,M,INDEX
      DOUBLE PRECISION A(340,33),R(33,33),Q(33,33),OMC(340),C(340)
C              LEAST SQUARES SOLUTION
C INPUT ARGUMENTS ARE A,NA,NQ,N,M.
C OUTPUT ARGUMENTS ARE R,Q,SE,OMC,C.
C
C
C INDEX IS THE ERROR COMPUTATIONAL SWITCH
C INDEX=0 MEANS SUCCESFUL TERMINATION
C INDEX=2 MEANS BAD N, OR M
C INDEX=3 MEANS Q(I,I)IS LESS THAN OR EQUAL TO ZERO
C TO SUPPRESS THE ERROR MESSAGE IF(Q(I,I)IS LESS THAN 0.. ENTER LSTSQRS
C WITH INDEX =0.,OR 1.
C IFQ(I,1)LE 0 THE COEFFICIENTS OF THE NORMAL EQUATIONS WILL STILL
C HAVE BEEN CORRECTLY FORMED AND RETURNED. LIKEWISE FOR ALL
C PREVIOUS Q(I,I) S AND THEIR Q(I,J)S WHERE J GT I.
C
C
C NOTATION
C
      DUM=1
C N=NUMBER OF UNKNOWNS PLUS 1
C M=NUMBER OF OBSERVATIONAL EQUATIONS OF CONDITION,
C A(K,J)= COEFFICIENTS OF THE OBSERVATIONAL EQUATIONS OF CONDITION
C          A(K,1)*X(1) +A(K,2)*X(2) +......+A(K,N-1)*X(N-1)
C        =A(K,N)
C  WHERE K=1,2,3,...,M
C R(I,J)= COEFFICIENTS OF THE NORMAL EQUATIONS, WHERE
C I=1,2,...,N-1 AND J=I,I+1,I+2,...,N,
C R(N,J)= STANDARD ERROR OF THE UNKNOWNS,J=1,2,...,N-1,
C Q(N,J)= X(J), THE UNKNOWNS  J=1,2,...,N-1
C Q(I,J)= THE WEIGHTS OF THE UNKNOWNS J=1,2,...,N-1,
C          AND I=J,J+1,...,N-1
C OMC(K)= OBSERVED-COMPUTED FOR ALL OBSERVATIONAL EQUATIONS,
C C(K)=COMPUTED VALUES FOR ALL OBSERVATIONAL EQUATIONS OF CONDITION
C       K=1,2,3,...,M
C SE=STANDARD ERROR OF A SINGLE EQUATION OF UNIT WEIGHT,
C   = THE SQUARE ROOT OF THE
C   =SUM OF ALL (O-C)**2 DIVIDED BY (M-(N-1));
C    (SE MULTIPLIED BY THE SQUARE ROOT   OF THE SUM OF THE
C   SQUARES OF THE WEIGHTS OF AN UNKNOWN IS THE UNKNOWN S
C   STANDARD ERROR)
C R(N,N)= SUM OF (O-C)**2 CALCULATED FROM OMC(K),K=1,2,...,M
C          (AND USED TO CALCULATE SE),
C Q(N,N)= SUM OF THE (O-C)**2 CALCULATED FROM THE IDENTITY --
C          (O-C)**2 =SUM OFA(K,N)*A(K,N) WHERE K=1,2,...,M
C          MINUS THE SUM OFQ(K,N)*Q(K,N) WHERE K=1,2,...,N-1
C          (NOT USED TO CALCULATE SE)
C NA=THE NUMBER OF ROWS IN THE A ARRAY AS DIMENSIONED IN THE
C     MAIN PROGRAM (M MUST BE LE TO NA)
C NQ= THE NUMBER OF ROWS IN THE N AND Q ARRAYS AS DIMENSIONED
C      IN THE MAIN PROGRAM( THE R AND Q ARRAYS SHOULD BE OF THE
C      SAME SIZE AND N MUST BE LE TO NQ)
C
C
```

```
C
      NM1=N-1
      IF((M.GE.NM1).OR.(M.LE.NA).OR.(N.LE.NO).OR.(N.GE.2))GO TO 20
      WRITE(6,2)
2     FORMAT(10X,'NO OF OBSERVATIONS LT NO UNKNOWNS OR TO HAVE EXCEED',
     1'ED DIMENSIONS OR NO OF UNKNOWNS LT 1')
      INDEX=2
      RETURN
C
C  CALC. COEFF. OF NORMAL  EQNS., R.
20    DO 30 I=1,N
      IK=I
      DO 30 J=IK,N
      R(I,J)=0.D0
      DO 30 K=1,M
30    R(I,J)=R(I,J)+(A(K,I)*A(K,J))
C
C CALCULATE TRIANGULAR SQUARE ROOT OF R CRACOVIAN AND THE RECRIP. FO
C ITS DIAGONAL ELEMENTS (EXCEPT IF I=N DONT TAKE ITS RECRIP.)
C
C
C EVALUATE Q(I,I).
      DO 120 I=1,N
      Q(I,I)=R(I,I)
      IM1=I-1
      IF(IM1.EQ.0)GO TO 41
      DO 40 K=1,IM1
40    Q(I,I)=Q(I,I)-(Q(K,I)*Q(K,I))
41      CONTINUE
      IF(I.EQ.N)GO TO 130
C
C  ERROR CHECK POINT 2
C
C
      IF(Q(I,I).GT.0.D0)GO TO 80
50    IF(INDEX.LT.2)GO TO 75
60     WRITE(6,61)
61    FORMAT(10X,'NEG ARG IN SQRT')
       WRITE(6,70)I,I,Q(I,I)
70    FORMAT(1X,/,10X,'THE SQUARE OF THE ',I2,'  ',I2,' ELEMENT OF THE',
     1'TRIANGULAR SQUARE ROOT OF THE',/,'10X,MATRIX-CRACOVIAN CONTAIN',
     2'ING THE COEFFICIENTS OF THE NORMAL EQUATIONS IS ',E15.6)
75    INDEX=3
      RETURN
C
C
80    Q(I,I)=1.D0/DSQRT(Q(I,I))
90    IP1=I+1
      IF(IP1.GT.N)GO TO 130
C  EVALUATE Q(I,J)FOR ALL J GT I
      DO 120 J=IP1,N
      Q(I,J)=R(I,J)
      IF(IM1.EQ.0)GO TO 101
      DO  100 K=1,IM1
100   Q(I,J)=Q(I,J)-(Q(K,I)*Q(K,J))
101   CONTINUE
120   Q(I,J)=Q(I,J)*Q(I,I)
C
C
C  EVALUATE Q(I,J) FOR ALL J LT I.
130   DO 160 J=1,N
      JP1=J+1
      IF(JP1.GT.N) GO TO 160
      DO 150 I=JP1,N
      Q(I,J)=0.D0
      IM1=I-1
```

```
      IF(IM1.EQ.0)GO TO 141
      DO 140 K=J,IM1
      Q(I,J)=Q(I,J)+(Q(K,I)*Q(K,J))
140   CONTINUE
141   CONTINUE
      IF(I.EQ.N)GO TO 160
      Q(I,J)=-(Q(I,J))*Q(I,I)
150   CONTINUE
160   CONTINUE
C CALC COMPUTED VALUES,(O-C). AND STD ERROR OF EACH EQN OF UNIT WT.
      R(N,N)=0.D0
C
      DO 180 K=1,M
      C(K)=0.
      DO 170 J=1,NM1
170   C(K)=C(K)+(A(K,J)*Q(N,J))
      OMC(K)=A(K,N)-C(K)
180   R(N,N)=R(N,N)+(OMC(K)*OMC(K))
C
      SE= DSQRT(R(N,N)/(M-NM1))
      NM2=NM1-1
C CALCULATE STD ERROR OF UNKNOWNS
      DO 200 J=1,NM2
      R(N,J)=0.D0
      DO 190 I=J,NM1
190   R(N,J)=R(N,J)+(Q(I,J)*Q(I,J))
200   R(N,J)=SE*DSQRT(R(N,J))
C
      R(N,NM1)=SE*Q(NM1,NM1)
C
      INDEX=0
      RETURN
      END
```

```
@FOR,IS READ
      SUBROUTINE READER
      COMMON /AB/ SE,CX(13),CY(13),CZ(13),THR(13),TMIN(13),
     1THETA(340),VEL(340),NINPRO,
     1X(340),Y(340),Z(340),T(340),
     1RANGE(340),CROSS(340),TEMP(340),PRES(340),
     1TRANGE(26),TCROSS(26),
     1TTEMP(26),TPRES(26),
     1NZONS(13),JZONS,NSITES
     1,NA,NB,NQ,N,M,INDEX
      DIMENSION HEADER(2),SITE(2)
C
C  LOCA?  VARIABLES
C
C  HEADER= ARRAY WITH SITE ID,DATE AND TIME READ FROM
C          _MASS STORAGE
C  SITE =  ARRAY CONTAINING SITE ID,DATA,AND TIME OF INTEREST
C  ITHETA,IVEL,ITEMP,AND IPREA ARE TEMPORARY VARIABLES
C  ALLOWING THE READING OF INTEGER VALUES
C
      JZONS=1
      DO 11 L=1,NSITES
      READ(5,201)CX(L),CY(L),CZ(L),THR(L),TMIN(L)
      WRITE(6,201)CX(L),CY(L),CZ(L),THR(L),TMIN(L)
C
C  CONVERT FEET TO METERS
C
      CX(L)=CX(L)*.3048
      CY(L)=CY(L)*.3048
      CZ(L)=CZ(L)*.3048
   11 CONTINUE
201   FORMAT(5(F8.0))
200   FORMAT(I2)
      DO 2 IK=1,NSITES
      REWIND 7
      READ(5,501)SITE(1),SITE(2)
501   FORMAT(2(A6))
C
C  SEARCH MASS STORAGE FOR SITE
C
1     READ(7,501)HEADER(1),HEADER(2)
      IF((HEADER(1).NE.SITE(1)).OR.(HEADER(2).NE.SITE(2)))
     1GO TO 1
      READ(5,200)NZONS(IK)
      NK=NZONS(IK)
C
C READ LAYERS
C
      DO 3 I=1,NK
      IF(NK.EQ.0)GO TO 3
      READ(7,300)ILEV,ITHETA,IVEL,ITEMP,IPRES
      THETA(JZONS)=ITHETA
      VEL(JZONS)=IVEL
      TEMP(JZONS)=ITEMP
      PRES(JZONS)=IPRES
300   FORMAT(I2,2(I3),I5,I4)
      JZONS=JZONS+1
3     CONTINUE
2     CONTINUE
      JZONS=JZONS-1
      RETURN
```

```
@FOR,IS COEF

      SUBROUTINE COEF
      COMMON /AB/ SE,CX(13),CY(13),CZ(13),THR(13),TMIN(13),
     1THETA(340),VEL(340),NI6PRO,
     1X(340),Y(340),Z(340),T(340),
     1RANGE(340),CROSS(340),TEMP(340),PRES(340),
     1TRANGE(26),TCROSS(26),
     1TTEMP(26),TPRES(26),
     1NZONS(13),JZONS,NSITES
     1,NA,NB,NQ,N,M,INDEX
C
C
C   ALL?_VARIABLES EXCEPT  _INDICES ARE IN COMMON
C
C   CHNGE VELOCITY TO METERS/MINUTE AND
C   UNSCALE TEMPERATURE AND PRESSURE
C
      DO 10 I=1,JZONS
      VEL(I)=VEL(I)*(.51444444*60.)
      TEMP(I)=TEMP(I)/10.
10    THETA(I)=(THETA(I))*10.
C
C   CONVERT FROM NAVIGATIONAL COORDINATE SYSTEM TO
C   MATHMATICAL COORDINATE SYSTEM
C
C
      IZ=1
      DO 20 K=1,NSITES
      NZ=NZONS(K)
      DO 20 IK=1,NZ
      I=IZ
      IF(THETA(I).GT.4800.) GO TO 30
      ANGL=4800.-THETA(I)
      GO TO 40
30    ANGL=(4800.-THETA(I))+6400
40    CONTINUE
      ANGL=(ANGL/6400.)*(2.*3.14159)
C
C RANGE IS THE NORTH,SOUTH COMPONENT OF THE WIND
C NORTH BEING POSITIVE
C
C
C CROSS IS THE EAT,WEST COMPONENT OF THE WIND
C EAST BEING POSITIVE
C
      RANGE(I)=SIN(ANGL)*VEL(I)
      CROSS(I)=COS(ANGL)*VEL(I)
      IF(IK.EQ.1)GO TO 21
      IF(IK.GT.4)GO TO 33
C
C X AND Y ARE DISPLACEMENTS COMPUTED USING VELOCITY AND TIME
C Z AND T ARE CUMULATIVE HEIGHT AND TIME RESPECTIVELY
C Z IS COMPUTED ASSUMING A CONSTANT RISE RATE OF 300 METERS PER SECOND
C
      IF(IK.EQ.2)X(I)=CROSS(I)*.33333
      IF(IK.EQ.2)Y(I)=RANGE(I)*.33333
      IF(IK.EQ.2)Z(I)=100.
      IF(IK.EQ.2)T(I)=.33333
      IF(IK.EQ.3)X(I)=(CROSS(I-1)*.33333)+(CROSS(I)*.5)
      IF(IK.EQ.3)Y(I)=(RANGE(I-1)*.33333)+(RANGE(I)*.5)
      IF(IK.EQ.3)Z(I)=250
      IF(IK.EQ.3)T(I)=.83333
```

```
      IF(IK.EQ.4)X(I)=(CROSS(I-1)*.5)+(CROSS(I)*.83333)
      IF(IK.EQ.4)Y(I)=(RANGE(I-1)*.5)+(RANGE(I)*.83333)
      IF(IK.EQ.4)Z(I)=400.
      IF(IK.EQ.4)T(I)=.5+.83333
      IF(IK.LE.4)GO TO 21
33    CONTINUE
      IF(IK.GT.12)GO TO 44
      X(I)=(CROSS(I-1)*.83333)+(CROSS(I)*.83333)
      Y(I)=(RANGE(I-1)*.83333)+(RANGE(I)*.83333)
      Z(I)=500.
      T(I)=1.66667
      GO TO 21
44    CONTINUE
      IF(IK.EQ.13)X(I)=(CROSS(I-1)*.83333)+(CROSS(I)*1.66667)
      IF(IK.EQ.13)Y(I)=(RANGE(I-1)*.83333)+(RANGE(I)*1.66667)
      IF(IK.EQ.13)Z(I)=750.
      IF(IK.EQ.13)T(I)=.83333+1.66667
      IF(IK.EQ.13)GO TO 21
      X(I)=(CROSS(I-1)*1.66667)+(CROSS(I)*1.66667)
      Y(I)=(RANGE(I-1)*1.66667)+(RANGE(I)*1.66667)
      Z(I)=1000.
      T(I)=3.33334
21    CONTINUE
C
C
C THE PROGRAM USES THE TIME AND POSITION OF THE FIRST
C STATION READ IN AS THE ORIGIN, THE FOLLOWING COMPUTES THE
C INITIAL OFFSET FOR EACH SUCCESSIVE STATION
C
C
      IF((IK.EQ.1).AND.(K.GT.1))X(I)=CX(K)-CX(1)
      IF((IK.EQ.1).AND.(K.GT.1))Y(I)=CY(K)-CY(1)
      IF((IK.EQ.1).AND.(K.GT.1))Z(I)=CZ(K)-CZ(1)
      IF((IK.EQ.1).AND.(K.GT.1))DELT=Z(I)*(1./300.)
      IF((IK.EQ.1).AND.(K.GT.1))TH=(THR(K)-THR(1))*60.
      IF((IK.EQ.1).AND.(K.GT.1))TM=(TMIN(K)-TMIN(1))
      IF((IK.EQ.1).AND.(K.GT.1))T(I)=TH+TM-DELT
      IF(IK.GT.1)X(I)=X(I)+X(I-1)
      IF(IK.GT.1)Y(I)=Y(I)+Y(I-1)
      IF(IK.GT.1)Z(I)=Z(I)+Z(I-1)
      IF(IK.GT.1)T(I)=T(I)+T(I-1)
      IZ=IZ+1
20    CONTINUE
      RETURN
      END
@MAP,IL  ,PREDICT/A
LIB NR-A*RBLIB.
@
```

sample data deck using four stations two times, and ten layers.

```
 4  2 10
 503109. 189735.   4033.     10.     00.
 557402. 189530.   4198.     10.     00.
 472572. 215268.   3999.     10.     00.
 543736. 140375.   4097.     10.     00.
 503109. 189735.   4033.     12.     00.
 557402. 189530.   4198.     12.     00.
 472572. 215268.   3999.     12.     00.
 543736. 140375.   4097.     12.     00.
11151000 TSX
10
11151000 ORO
10
11151000 SMR
10
11151000 MCG
10
11151200 TSX
10
11151200 ORO
10
11151200 SMR
10
11151200 MCG
10
010005
```

SAMPLE OUTPUT

```
@XQT PREDICT/A
@ADD FL.DATA/NEW
 503109.      189735.      4033.     10.      0.
 557402.      189530.      4198.     10.      0.
 472572.      215268.      3999.     10.      0.
 543736.      140375.      4097.     10.      0.
 503109.      189735.      4033.     12.      0.
 557402.      189530.      4198.     12.      0.
 472572.      215268.      3999.     12.      0.
 543736.      140375.      4097.     12.      0.
    1   4730.000              6.000     288.3      875.
    2   3660.000              2.000     290.7      865.
    3   4200.000              4.000     288.6      840.
    4   4650.000             13.000     284.8      810.
    5   5020.005             16.000     285.0      745.
    6   4724.610             38.209     283.2      708.
    7   5329.776             43.313     279.8      666.
    8   4670.980             41.689     276.0      626.
    9   4802.574             60.206     272.2      589.
   10   4816.960             57.369     268.2      554.
```

FILMED

8